Course Title: **Radiological Control Technician**
Module Title: **Counting Room Equipment**
Module Number: **2.19**

Objectives:

☞ 2.19.01 Describe the following features and specifications for commonly used laboratory counter or scalers:
a. Detector type
b. Detector shielding
c. Detector window
d. Types of radiation detected and measured
e. Operator-adjustable controls
f. Source check
g. Procedure for sample counting

☞ 2.19.02 Describe the following features and specifications for low-background automatic counting systems:
a. Detector type
b. Detector shielding
c. Detector window
d. Types of radiation detected and measured
e. Operator-adjustable controls
d. Source check
e. Procedures for sample counting

☞ 2.19.03 Describe the following features and specifications for commonly used gamma/alpha spectroscopy systems used at your facility:
a. Detector type
b. Detector shielding
c. Detector window
d. Types of radiation measured
d. Procedures

References:

1. Radiation Detection and Measurement, Glenn F. Knoll
2. Basic Radiation Protection Technology, Daniel A. Gollnick
3. Operational Health Physics, Harold J. Moe
4. ANSI N323A
5. (Various Manufacturers Technical Manuals)

Instructional Aids:

1. Overheads
2. Overhead projector and screen
3. Chalkboard/markerboard
4. Lessons learned

I. MODULE INTRODUCTION

A. Self Introduction

1. Name

2. Phone number

3. Background

4. Emergency procedure review

B. Motivation

In this lesson, we will cover counting room equipment in relation to types used, purpose for, radiation monitored, operational requirements, and specific limitations and characteristics. The RCT uses information from these counting instruments to identify and assess the hazards presented by contamination and airborne radioactivity and establish protective requirements for work performed in radiological areas.

C. Lesson Overview

1. General principles

2. Laboratory counters or scalers

3. Low-background automatic systems

4. Gamma Spectroscopy

D. Introduce Objectives

O.H.: Objectives

NOTE: Text is provided for some commonly used simple counting systems. Adjust text as necessary for instruments used at the site.

II. MODULE OUTLINE

A. Introduction

1. An overview of counters, scalers and associated equipment will describe the basic functions of counting equipment used to detect radiation activity.

2. The RCT uses information from these counting instruments to:

   a. identify and assess the hazards presented by contamination and airborne radioactivity and;

   b. establish protective requirements for work performed in radiological areas.

3. Stand-alone counters or scalers measure gross activity while spectroscopy systems perform spectrum analysis to identify and quantify activity from specific nuclides.

4. The common uses of counting room equipment in various facilities will be discussed.

5. A variety of counting equipment is used, both manual and automated.

   a. Shielded equipment to measure radioactivity just above background levels.

   b. Equipment to measure gross counts of alpha, beta and gamma to determine if surface contamination limits are met.

   c. Equipment to measure the energy spectrum for alpha and gamma radiation so that individual isotopes can be identified and quantified (e.g. to determine if an alpha emitter is a plutonium isotope, a uranium isotope or a radon daughter).

6. The counting systems use various types of detectors, including:

   a. gas proportional counters for alpha and beta radiation;

b. sodium iodide, scintillation detectors for gamma spectroscopy;

c. zinc sulfide (ZnS) scintillation detectors for alpha radiation;

d. liquid scintillation for tritium and carbon 14;

e. surface barrier (semiconductor) detectors for alpha spectroscopy,

f. lithium drifted germanium (GeLi semiconductor) detectors for gamma spectroscopy,

g. high purity, germanium (HPGe semiconductor) detectors for gamma spectroscopy.

7. The most common uses of the equipment are to count:

   a. Smears and swipes

   b. Air filters

8. Nose swipes are also counted as one way to test if an individual has been exposed to airborne radioactive contamination.

9. Both workplace and stack emission air filters are counted to measure the concentration of specific radionuclides (e.g. plutonium, and uranium) and classes of radionuclides (e.g. mixed fission products).

B. General Principles

A variety of counting room systems are used. The principles of these systems will be discussed in general and then specific systems will be described.

1. Detector Type

   a. When looking for low levels of radioactivity from alpha emitters (e.g. U, Pu, etc.) it is important to minimize the background count rate from betas and gammas.

b. The principle used to accomplish this is pulse height discrimination.

c. Betas have a range that is about 100 times greater than alphas, so alphas will deposit about 100 times as much energy in a thin detector, producing a larger pulse than betas. Therefore alpha detectors are thin (typically 1 mg/cm^2) and use pulse height discrimination to distinguish alphas from betas.

d. Alpha detectors are generally either gas proportional counters, ZnS scintillators, or silicon semiconductors.

e. Gamma spectroscopy requires good resolution to distinguish the different energy peaks. GeLi or HPGe semiconductors give the best resolution, though NaI scintillators are also used.

2. Detector Shielding

   a. To reduce the background, shielding is often used.

   b. Betas can be shielded with aluminum or plastic.

   c. Typical gamma shielding is a few inches of lead.

3. Detector Window

   a. Since alphas have a short range the windows are thin, typically 1 mg/cm^2 (or 0.25 mil plastic).

   b. Some detectors have no window between the sample and the detector; in this case there is a gas purge system for gas proportional counters, or a light tight housing for scintillators.

   c. The alpha range is so short that self-shielding is often significant, e.g. an alpha emitter buried in a filter may be shielded from the detector by the fibers.

4. Types of Radiation

   a. Some of the detectors discussed in objectives 1 and 2 are designed for alphas, some for betas, and some will count both.

b. Gamma spectroscopy is discussed in objective 3.

c. Most nuclides emit more than one type of radiation, but beware of exceptions (like Be-7 or C-14).

d. Beta background is greater than alpha, so alpha detectors use pulse-height discrimination to differentiate between alphas and betas.

e. Some gammas will generally be detected in these detectors, but thin detectors have low gamma efficiency, and lead shielding helps to reduce the gamma background still further.

5. Operator Adjustable Controls

   a. Counting room systems have a timer to allow the operator to measure the number of counts per minute (cpm).

   b. The most common count time is 1 minute, but the count time can be selected by the operator.

6. Sources

   a. National Institute of Standards and Technology (NIST) standard sources are used to check the systems.

   b. Common sources are:

      1) Pu-239 for alpha

      2) Sr-90 for beta

7. Procedures

   a. Procedures generally include:

      1) background count

      2) source check

      3) sample count

4) background subtraction

5) divide by time to get cpm

6) correct for 4 pi efficiency to get dpm

7) record the data

B. Laboratory Counters or Scalers

Objective 2.19.01

In this section, specific laboratory counters or scaler systems are discussed, illustrating the general principles discussed above.

1. Sample Holder SH-4 with HP210 and ESP

a. The simplest system for counting smears is the portable contamination survey instrument, the Eberline smart portable ESP with hand probe HP210. ESP means Eberline Smart Portable. HP means Hand Probe.

b. Recall from lesson 2.17 that the HP-210 probe is a pancake GM detector with a thin (1.4 to 2 mg/cm^2) window, suitable for detecting beta contamination, and alphas above 3 MeV. Window is thicker than most alpha detectors, so probe must be < 1/4 inch from source of alphas.

1) The HP210T is shielded with tungsten to reduce gamma background.

Shield gammas with high Z material.

2) The HP210AL is shielded with aluminum to reduce beta background.

Shield betas with low Z material.

c. The problem with using the HP210 for quantitative measurements (e.g.to satisfy release criteria) is one of ensuring a precise geometry.

d. The SH-4 sample holder solves this problem by holding the sample in a fixed position directly under the HP210 detector.

2. Eberline Scintillation Alpha Counter SAC-4

   a. The Eberline SAC-4 is a scintillation alpha counter. S.A.C. is an acronym

      1) The scintillation phosphor is ZnS powder on a plastic light pipe.

      2) The system is a self contained unit with the detector and associated electronics housed in a single unshielded box.

      3) The detector and sample are both in a light tight can, so no window is required between the ZnS detector and the sample.

   b. The system will accept samples up to 2 inches in diameter by 3/8 inches thick. (Self shielding would be a major problem with samples this thick.)

      See lesson 2.03

      1) The sample holder in the slide drawer is adjustable. It can be moved closer to the detector for thin samples.

      2) The SAC-4 is calibrated with the sample holder in a certain position, so if the sample holder is moved, the calibration is no longer valid.

   c. The electronic package consists of the high voltage power supply used to power the photomultiplier tube and determine its amplification, and a linear amplifier. Amplifier output is 0 to 10 V

      1) Only pulses with amplitudes above the discriminator level will be counted. Discriminator level is 1.25 V

      2) This will discriminate against betas because they will produce smaller pulses.

   d. The output from the discriminator is counted by a six decade light emitting diode (LED) readout.

1) The timing circuit is synchronized to the line frequency (60 Hz) and provides preset counting times from 0.1 to 50 minutes controlled by front panel switches.

2) This scaler can also be operated in a manual mode which will continue to count until reset by the operator.

e. A Pu-239 source is used to check the system prior to each operating shift.

1) Background counts are conducted as a part of the performance check and to check for detector contamination.

2) The detector and sample drawer are easily removed for decontamination if required.

f. The gross count rate is obtained by dividing total counts by the time in minutes.

1) Background counts (typically 0.3 cpm) are subtracted from gross counts to obtain net counts per minute (cpm).

2) The net count rate (cpm) is corrected for efficiency to convert cpm to disintegrations per minute (dpm).

See lesson 2.03

g. This counting system is used to obtain total activity and the procedures are followed as described in the SAC-4 manual. Each background, source count, and sample count is documented and kept on file.

3. NMC PC-5 and PC-55

Nuclear Measurement Corporation

a. The PC-5 and PC-55 systems use gas flow proportional counters as the detectors.

1) The gas used is P-10 (90% argon and 10% methane).

2) The systems are self-contained units with the detector and associated electronics housed in the same box.

3) The PC-55 is used to count both alpha and beta.

4) The PC-5 may be manually adjusted to count either alpha or beta. It is normally set to count alpha only.

5) The determination of an alpha count or a beta count is accomplished by pulse height discrimination.

b. No external shielding is used.

1) Typical background for the unshielded detector is 2 cpm for alphas, and 60 to 100 cpm for betas.

c. The PC-5 and PC-55 have identical detectors, 2.25 inch in diameter.

1) They may be installed with thin plastic windows with a thickness of 0.25 mil (0.00025 inch, 1 mg/cm^2) or they may be installed with no window.

2) If there is no window, the operator must purge with P-10 gas after inserting a sample and closing the gas tight door.

d. Front panel controls allow for pre-set gas purge times of 12, 36 and 144 seconds.

1) If the detector is installed with a thin plastic window, the normal procedure is to flow the gas continually.

Window is optional

e. The sample to be counted is placed in a 2 inch diameter planchet and placed in the sample drawer.

1) The sample drawer then slides the sample under the detector.

2) Should the detector drawer or sample holder become contaminated during counting, it is a simple task to remove the detector and drawer for decontamination.

f. The high voltage supply has a dual operating range of 300 - 1300 volts and 1300 - 2300 volts controlled from a front panel voltage potentiometer. RCTs do not normally adjust this.

1) The high voltage determines the optimum setting to discriminate alphas from betas.

g. The count time is also set by front panel switches providing pre-set counting times in 0.1 minute increments up to 1000 minutes.

1) In the automatic mode, the counter will count to the pre-set time interval.

2) In the manual mode, the counter will continue to count until manually reset.

h. Two sources are used to check the system for proper operation.

1) The alpha source is Pu-239 electroplated on a nickel disc.

2) The beta source is $^{90}Sr/^{90}Y$ (Strontium-90 and its daughter, Yttrium-90).

3) These sources are traceable to NIST (National Institute of Standards and Technology).

C. Low-background Automatic Systems — Objective 2.19.02

1. In this section, several automatic counting systems are discussed.

a. The principles are the same as in section 1 (objective 1).

b. The essential differences between the systems in sections 1 and 2 are:

1) Complexity of electronics

2) number of detectors or automated sample changing

3) shielding to reduce background

2. Canberra 2400

   a. The Canberra 2400 is a low background automatic counting system.

      1) The primary detector is a gas flow proportional counter with a 2.25 inch diameter thin window, used to count both alpha and beta activity. Proportional counters use pulse height discrimination.

      2) A second larger proportional counter, the guard detector, is used to count background.

      3) The gas used is P-10 (90% argon and 10% methane).

      4) The system may also incorporate a NaI scintillation detector, an option with the Canberra 2400 systems, to simultaneously count gamma rays.

   b. The sample detectors are surrounded by 4 inches of lead shielding to reduce background.

      1) Typical background is 0.1 to 1 cpm alpha, 1 to 5 cpm beta, and 100 to 400 cpm gamma.

   c. Canberra 2400 systems are used principally to count smears and filters.

      1) Gross counts for each sample are processed in the computer and converted to dpm.

      2) Smear counts above preset limits are highlighted and printed on a separate report.

d. Performance checks are performed daily or prior to system use. NIST traceable sources of:

1) Pu-239 (Plutonium),

2) Sr-90 (Strontium), and

3) Tc-99 (Technetium) are used.

e. The system has an automatic sample changer with a dual stack that can handle up to 100 samples.

1) One stack holds the samples to be counted and the other stack stores the samples that have been counted.

3. Berthold LB770

a. The Berthold LB770 counting system is a low background semi-automatic counting system.

1) The system uses eleven P-10 gas flow proportional detectors;

2) ten detectors are used to count 10 radioactive samples simultaneously,

3) the other detector is used to count background radiation.

b. Each detector has a 2.25 inch diameter by 0.25 mil (0.00025 inch) mylar window.

1) The detector bay is shielded with 4 inches of epoxy coated lead.

2) Typical backgrounds are 0.1 cpm alpha and 1 or 2 cpm beta.

3) Typical counting efficiencies are 27% alpha and 42% beta.

4) The planchet is 0.25 inch deep, but a 0.25 inch thick sample would cause major self-shielding problems. Self shielding: see lesson 2.03.

c. The Berthold systems are used primarily to count smears or filters.

   1) Both alphas and betas are counted simultaneously in each detector.

   2) Determination of alpha or beta activity is accomplished by pulse height discrimination.

   3) The scalers in the Berthold systems are similar to those used in the PC-55 but with more sophisticated electronics that provide improved pulse shaping from the linear amplifier and better discrimination of both pulse amplitude and pulse shape.

d. Plutonium-239 sources are used to check the system for alpha and $^{90}Sr/^{90}Y$ sources are used to check for beta. Yttrium-90 is the daughter of Strontium-90.

   1) These sources are traceable to NIST

e. The Berthold system is controlled by a computer.

   1) Both alpha and beta counts received from each sample are corrected for background and reported in one of three categories, to alert the operator.

   2) If the count rate is below the minimum detectable activity (MDA, see lesson 2.03) it falls into category 1.

   3) A count rate that falls within predetermined limits, usually above MDA but below the limit for release to a controlled area (RadCon table 2.2) is category 2. MDA stands for Minimum Detectable Activity, see lesson 2.03.

   4) A count rate that is higher than the upper limit is category 3.

f. Background and efficiency data are collected for each detector, stored and used for corrections.

1) Pre-set count times are determined by the operator and put into the computer.

2) The count rate data from each detector is corrected and converted to dpm for output to the printer.

4. Liquid Scintillation Counters, LSC

e.g. Packard 2550

a. Tritium and C-14 emit such low energy betas that even a thin layer of air would stop the betas.

1) To detect this radiation, the sample must be in intimate contact with the detection medium.

2) This is achieved with a liquid scintillation system.

b. A liquid scintillation counting system uses a "cocktail" that immerses the sample in the counting medium to maximize the detection efficiency for low energy beta emitters.

1) This cocktail includes a liquid scintillator to convert the energy deposited by low energy betas into light photons, which are then counted using photomultipliers.

c. The sample chamber, containing the sample vial and photomultiplier tubes, is light tight.

1) Since stray electrons can be spontaneously emitted from the photocathode, or by the dynodes in the photomultiplier tube, two tubes are used with coincidence circuitry to reduce this source of noise called "dark current".

2) Typical background for beta is 20 cpm.

d. The LSC system is typically used to count tritium samples from swipes, water samples, and oil samples (vacuum pumps).

1) Tritium is also collected by drawing air samples through silica-gel traps or glycol bubblers.

e. To calibrate the system, a series of cocktails with known amounts of tritium are prepared.

1) These sources are loaded into the first sample holder (a tray of 10 sample vials).

2) The computer program calculates the detector efficiency for each calibration source.

D. Gamma Spectroscopy

Objective 2.19.03

1. The instruments discussed in objectives 1 and 2 are designed to detect alphas and/or betas, and make a gross count of total alpha and beta activity.

   a. In order to identify specific radionuclides, the unique spectrum of energies particular to each radionuclide is used.

   b. This technique is known as spectroscopy.

2. Alpha emitters (e.g. Th, U, Pu, Am and their daughters) have characteristic alpha energies, but alpha spectroscopy, detecting the alphas directly, is not optimal, because the energy loss of alpha particles between the sample and the detector smears the energy spectrum.

3. Gamma spectroscopy usually uses germanium detectors (GeLi or HPGe) because the good resolution obtained with these detectors enables gammas with nearly the same energy to be distinguished or resolved.

4. EG&G Ortec Gamma X

   a. The Gamma X Spectroscopy system uses an HPGe coaxial photon detector to perform gamma and x-ray spectroscopy in the energy range from 3 keV to 10 MeV.

   b. Detector Type

      1) The detector is made of n-type high purity germanium semiconductor (HPGe).

2) A 30 liter dewar of liquid nitrogen (LN_2) is used to cool the detector.

c. Detector Shielding

1) The detector is shielded by 4 inches of pre World War II steel.

2) This steel is used when a low background is desired as it was manufactured before radioactive fallout from nuclear weapons appeared in trace quantities.

3) A sample holder inside the shield allows the sample to be positioned at distances from less than 1 cm up to 40 cm from the detector end cap. Artificial radioactivity is discussed in Lesson 1.06.

d. Detector Window

1) The detector window is 0.5 mm thick beryllium.

e. Types of Radiation Measured

1) The gamma spectrometer is designed to detect gammas and x-rays from alpha emitting nuclides, and sort the data in a multi channel analyzer to produce a spectrum that is characteristic of the nuclide.

2) The peaks in the spectrum are close together, so excellent resolution is required to distinguish the peaks.

3) Typical resolution from a germanium semiconductor detector (HPGe or GeLi) is better than 1%, which means that if the photon energy is 100 keV, the width of the peak is less than 1 keV.

4) Photons from two different nuclides that are 1 keV apart will be seen as two distinct peaks.

f. Procedures

1) Energy and efficiency calibrations are obtained using two different sources that are NIST standards.

2) These are mixed sources that contain several gamma emitting nuclides.

3) One source contains isotopes of Americium (Am), Antimony (Sb), and Europium (Eu).

4) The second mixed source contains isotopes of Cadmium (Cd), Cerium (Ce), Cobalt (Co), Strontium (Sr), Tin (Sn), Cesium (Cs), and Yttrium (Y). These sources provide several calibration energies.

5) The energy and efficiency calibration values are then used by the analysis software.

6) Specific procedures are written to direct the operator through the sample and computer setup, and the computer analysis.

7) The original copy of the results is kept on file for 1 year and then archived for 75 years.

III. SUMMARY

A. Review major points

1. General principles

2. Laboratory counters or scalers

3. Low-background automatic systems

4. Gamma Spectroscopy

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% should be the minimum passing criteria for examinations.